Brown Bag Abstract: Advanced eye movement technology for operational deployment

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The ability to measure voluntary and automatic eye movements in operational environments provides opportunities for unobtrusive assessment of vigilance and physiological status, whether under the sea, on land, in aircraft or in space. This presentation outlines current and potential applications of small high speed digital camera sensors to monitor coordinated eye movement and pupil adjustments real-time and provide reliable information on cognitive and neurologic performance. The current state-of-the-art for clinical applications includes algorithms for (1) eye/[pupil size tracking and assessment of their performance of voluntary (e.g., saccades and smooth pursuit) and automatic (e.g., vestibulo-ocular response) eye movements and (2) assessing gaze timing and dynamics. Reflex eye movement timing parameters are modified predictably by concurrent tasks. [1] Recent developments with stereoscopic heads-up displays allow assessment of eye movements associated with tracking in three dimensions, particularly the convergent eye movements and dynamic pupil constriction when viewing approaching objects. The convergent eye movement paradigms are very promising for assessment of mild concussion. These technologies can now be refined and embedded in undersea, surface and air operational platforms to both monitor warfighter physiological status and inform decision support interventions.

Quantitative assessment of oculomotor and vestibulo-ocular performance for conjugate eye movements has been a mainstay of advanced diagnosis in neurology, neurotology and neuro-ophthalamology for several decades. As a result, there are extensive normative data bases for motor performance, as well as diagnostic criteria based upon quantifiable performance features. Eye movement performance can also be used to assess aspects of drowsiness, attention, vigilance and cognitive performance in a number of test paradigms, which include tests of spatial memory and executive function. For example, when one becomes drowsy, the velocity profile of saccadic eye movements is slowed and the regularity of optokinetic nystagmus deteriorates. We have shown recently that high frequency vestibulo-ocular reflex performance parameters and performance on two saccadic tasks within cognitive tests are sufficient to differentiate control subjects from acute mild TBI patients with high sensitivity (89%) and specificity (95%). [2] It has proven useful in assessment of recent incidents involving the Department of State.

The portability of the technology permits objective, point-of-injury assessment of the degree of impairment of a warfighter from energy directed at the head. This early information will be valuable for designing and assessing efficacy of protective measures at the site of exposure.

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[1] Balaban, CD, Furman JM. Beat-to-beat control of human optokinetic nystagmus slow phase durations. J Neurophysiol 117: 204–214, 2017. doi:10.1152/jn.00342.2016.

[2] Balaban C, Hoffer ME, Szczupak M, Snapp H, Crawford J, Murphy S, et al. (2016) Oculomotor, Vestibular, and Reaction Time Tests in Mild Traumatic Brain Injury. PLoS ONE 11(9): e0162168. doi:10.1371/journal.pone.0162168

Technologies for eye movement measurement have evolved from DC electro-oculography, based upon measurements of shifts of the ocular dipole, to scleral magnetic search coil and more recent video-oculographic methods. The scleral search coil methods have been a 'gold standard' for measuring vertical, horizontal and torsional movements with temporal (~1 kHz sample rate) and spatial precision. (<0.1 degree). These methods are necessarily laboratory-based, because the patient is seated at the center of an alternating magnetic field and the current induced in a contact lens-mounted coil measures the eye movements. With advances in microelectronics, video-oculographic systems can be upgraded to match the performance specifications of the search coil methods. Since the pupil area is monitored, as well, one can measure simultaneously (1) eye movement dynamics, (2) pupil control dynamics and (3) coordination of eye and pupil movements. We have recently demonstrated that coordinated eye convergence movements and pupillary constriction can be quantified in control subjects and mild TBI patients for differential diagnostic applications. Since pupil responses are also indicators of oxygenation status at high altitudes, the clinical technology shows considerable promise for applications in a number of operational environments for unobtrusively monitoring physiological status and vigilance.[3]

[3] Wilson MH, Edsell M, Imray C, Wright A; Birmingham Medical Research Expeditionary Society. Changes in pupil dynamics at high altitude--an observational study using a handheld pupillometer. High Alt Med Biol. 2008 Winter;9(4):319-25. doi: 10.1089/ham.2008.1026

Schultheiss M, Schommer K, Schatz A, Wilhelm B, Peters T, Fischer MD, et al. (2014) Pupillary Light Reaction during High Altitude Exposure. PLoS ONE 9(2): e87889. doi:10.1371/journal.pone.0087889